

## SINGLE MASK CONTROL OF DOPING LEVELS

### Field of the Invention

The invention relates to a method of controlling doping levels in an integrated  
5 circuit. It also relates to a method of controlling the breakdown voltage between the  
active region and the substrate of a snapback device.

### Background of the Invention

Recent trends in integrated circuits is the inclusion of all analog functional blocks  
10 in a single chip. In doing so, however, consideration has to be given to the fact that there  
are different voltage requirements for different functional blocks on a chip. For instance,  
the power supply voltage will typically be quite different from the signal voltage of the  
input and output signals. The analog blocks may therefore be required to provide the  
necessary power supply for certain output devices such as USB devices. This is seen, for  
15 example, in the automotive industry where new standards require a supply voltage level  
of 42 V. Thus integrated circuits, which now abound in motor vehicles, have to be  
compatible with the particular power supply level.

The need for a cost-effective solution becomes particularly significant in the case of low  
cost electronics such as imaging and low cost sensors. Using high voltage processes for  
20 such applications is therefore economically not feasible. An alternative approach is to  
use a multiple chip solution to perform the voltage conversion. However, this is not only  
cumbersome but also costly.

A cost effective solution to handling different voltage levels is therefore required.  
For example, National Semiconductor Corporation deals with bi-directional ESD  
25 protection devices implemented in a 5 V process that have to provide 60V ESD  
protection at the input pads while the core of the chip still uses 5V.

More generally, it is desirable to be able to provide a semiconductor chip with  
different functional blocks operating at different voltage levels or having different  
breakdown voltages. Furthermore it is desirable to achieve this without having to incur  
30 additional process steps, such as additional mask or doping steps.

### Summary of the Invention

The present invention provides a method of varying doping levels across an integrated circuit (IC) by using a perforated mask with varying ratios of masked portion  
5 to unmasked portion. Thus some regions of the mask will have more unmasked portions to allow more dopant to pass through the mask, and some regions will have more masked portions and block more of the dopant.

Further, according to the invention, there is provided a method of varying the breakdown voltages of snapback devices on an integrated circuit by using a mask of  
10 varying degrees of perforation during formation of isolation layers. This allows the dopant concentration to be varied for isolation layers between, for example, a well and a substrate.

Still further, according to the invention, there is provided a method of controlling the breakdown voltage of a snapback device, comprising controlling doping levels of an  
15 isolation region by using a perforated mask during doping of the isolation region.

Still further, according to the invention, there is provided a method of increasing the breakdown voltage of a snapback device (e.g., an ESD protection or high voltage device) comprising forming an isolation layer between active regions (e.g. n-wells) and  
20 substrate of the device, by means of spotted implants. The spotted implants are typically achieved by making use of a mask with intermittent openings. Preferably the spotted implants are provided before one or both of an epitaxial layer being grown and high diffusion drive taking place.

Still further, according to the invention, there is provided a method of controlling the doping level of a doped region in an integrated circuit, comprising using a perforated  
25 mask during doping of the doped region, with the mask having a predefined ratio of perforation to mask material.

### Brief Description of the Drawings

Figure 1 shows a sectional view of a typical DIAC ESD device without isolation layer,

5 Figure 2 shows a sectional view of a typical DIAC ESD device with isolation layer,

Figure 3 shows a sectional representation of a snapback device showing a process step of the invention involving a perforated mask,

Figure 4 shows a sectional representation of a snapback device showing a process step of the invention illustrating the dopant implantation,

10 Figure 5 shows the device of Figure 4 after high diffusion drive,

Figure 6 shows the device of Figure 5 after the remaining process steps have been completed, and

Figure 7 shows current against voltage curves for a device of the invention compared to prior art devices.

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### Detailed Description of the Invention

The present invention provides a way of controlling the doping level for a particular region of a device. For example, an isolation region with a particular doping  
20 density can be formed between an active region and a substrate of a snapback device such as a DIAC. This is achieved by making use of a perforated mask to act like a sieve or filter, thereby limiting the amount of dopant that the region is exposed to. By appropriately choosing the ratio of unmasked to masked portion over the device region (i.e. by controlling the size and density of the perforations in the mask), the present  
25 invention achieves a desired doping density.

In choosing the perforation size and spacing between perforations, the typical distribution profile of dopant in the semiconductor material is taken into consideration. As the dopant diffuses into the semiconductor material it assumes a Gaussian distribution profile in all three dimensions, as a function of time and temperature. Thus, annealing the  
30 doped region causes the dopant to spread out in Gaussian manner. In order to ultimately

achieve a relatively uniform continuous doped region under the perforated mask of the invention, the perforations (unmasked portions) have to be closer than the ultimate doping diffusion. Thus process steps such as high diffusion drive and subsequent epitaxial growth, contribute to the distribution of the dopant.

5       As mentioned above, the Gaussian distribution profile extends not only laterally, but also vertically. Therefore shallower implants with less room for vertical diffusion cannot be exposed to as much annealing. Hence, to achieve a continuous doped layer, the perforations in the mask have to be closer together than is possible with deep implants.

10       The invention also provides a way of achieving different doping levels across different regions of a single integrated circuit. In particular, it achieves this by using a single mask and providing different size perforations in the mask. In other words the mask is etched differently in different regions to provide for larger or more numerous perforations (unmasked portions) in some regions than in others. By appropriately choosing the ratio of unmasked to masked portion over the device region, the present  
15       invention achieves a desired doping density. This will be described in more detail with reference to Figures 3 and 4.

As mentioned above, one application of the invention is in providing the appropriate doping level to a particular isolation region. Also it allows different regions for different devices on a single integrated circuit to be provided with different doping  
20       levels by making use of different masks or using a single mask with different numbers and sizes of perforations per unit area. In accordance with the invention, this allows the breakdown voltage of devices to be controlled. When compared to a prior art DIAC device (see Figure 2) which has a solid isolation region, the present invention allows the breakdown voltage to be increased by reducing the doping level of the isolation region.  
25       The effect is shown in the curves of Figure 7, which will be discussed in greater detail below. It will be appreciated that the breakdown voltage can thus be adjusted by adjusting the size and density of the perforations in the mask during doping of the isolation region. This will become clearer in the discussions that follow below.

Figure 1 shows a prior art DIAC 100 that has p-wells 102 formed in a substrate  
30       104. No isolation region is provided in this device, and the device therefore suffers from

substantial leakage. In contrast, the prior art device shown in Figure 2 shows a DIAC 200 with an isolation region 202 between p-wells 204 and substrate 206. This provides a snapback device with current density versus voltage characteristics as shown by curve 702 in Figure 7. As can be seen by the curve 702, the breakdown voltage for the device  
5 200 is approximately 35 V.

According to the present invention, this breakdown voltage can be increased by making use of a periodically masked isolation layer. In one embodiment, which made use of ratio of 2000/500 for masked portion to unmasked portion, a breakdown voltage of about 50V was achieved, as shown by the curve 704 in Figure 7.

10 One approach to achieving such a periodically masked isolation layer is shown in Figures 3-6. Figure 3 shows a p-substrate material 300 before n-epitaxial growth. In accordance with the invention, a periodic mask 302 (comprising photoresist with perforations or openings) is formed over the substrate 300. In this embodiment the photoresist material 306 periodically alternates with perforations or openings 308. By  
15 adjusting the width W of the photoresist regions 306 and the gap size G of the openings 308, the density and number of gaps or perforations can be varied per unit area. This will effect the amount of dopant that passes into the substrate as will become clear from Figure 4. In this case phosphorus was used as the dopant to form spotted implant regions 400 of n-material in the substrate (Figure 4).

20 As shown in Figures 5 and 6, by making use of high temperature process steps, such as long-term high temperature diffusion during the drive of phosphorus impurities, or by subsequent annealing, the spotted implants form a more uniform region to define an isolation layer 600 between the p-substrate 300 and active regions in the form of p-wells 602. As mentioned above, the Gaussian distribution of the diffusion is a function of  
25 time and temperature. Thus, all steps following the diffusion will change the profile. However, an important aspect in determining the final diffusion dimensions is determined by the high diffusion drive and any subsequent epitaxial growth. As also discussed above, in the case of shallow implants, the anneal time and/or the temperature will have to be reduced. It will be appreciated that there may be more than one annealing step, each  
30 at a different temperature and performed for a different time. The annealing steps may be

additional steps performed or may form part of the regular process of forming the device, such as epitaxial growth of a region.

While the embodiment discussed above provided for forming of the isolation layer before epitaxial growth, the isolation layer could also be formed after epitaxial growth by making use of high diffusion drive.

In the embodiment of Figures 3-6 a certain ratio of W to G was used. As part of the invention, the doping density of the isolation layer can be adjusted by adjusting this ratio. The table below shows the results for different ratios, showing how breakdown voltage changes. The table also shows a prior art fully blocked device (mask has no perforations and therefore no isolation layer is formed, which accounts for resistive leakage at 0V) and a prior art unblocked or fully opened device (mask is eliminated and a highly doped isolation region is formed) for comparison.

By providing an isolation layer, the present invention also provides for a device that is bi-directional. Some of the breakdown voltages for negative pad voltages, are also shown in the table below.

Number	Breakdown voltage	Blocked region W ( $\mu\text{m}$ )	Unblocked (open) region ( $\mu\text{m}$ )
1	Leakage from 0V	Fully blocked	0
2	44.2	1	1
3	45.7	0.5	0.5
4	48.9	0.6	0.4
5	43.3/-43.2	2	2
6	49.3	2	1
7	39.7/-39.6	1	2
8	51.4/-51	0.2	0.2
9	Leakage from 4V	2	0.2
10	Soft punch through from 40V	3	0.5

11	64.4/-25	2	0.5
12	35/-35	0	Fully open

5       The embodiment discussed above dealt with forming an isolation layer of  
 controlled impurity density. It will be appreciated that the invention could also be used to  
 control the density of impurity implantation into any other regions in one or more devices  
 on an integrated circuit.

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